Discovery of exceptionally strong electron-capture transition sheds new light on the fate of intermediate-mass stars

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on behalf of

I230 collaboration at JYFL-IGISOL

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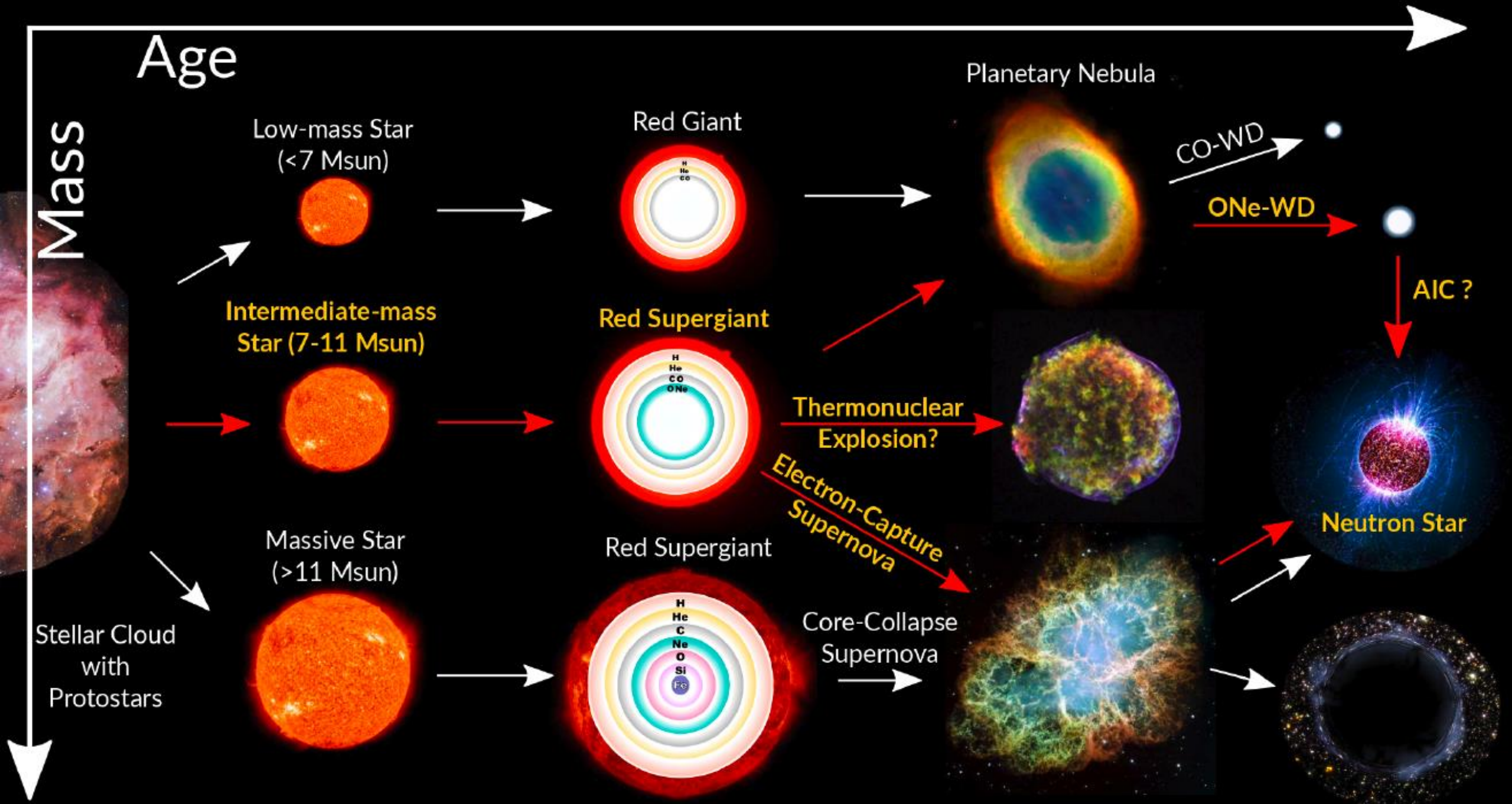
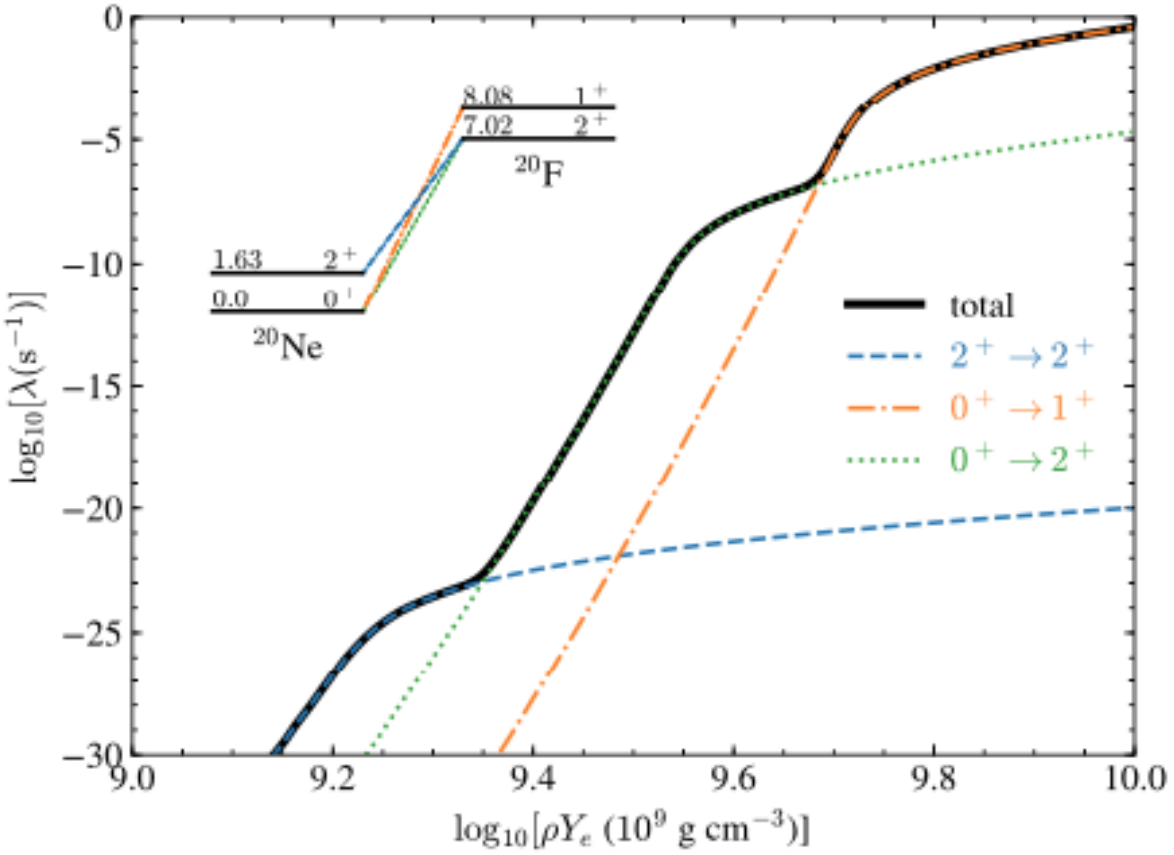

Age
Mass
Low-mass Star
(<7 Msun)
Red Giant
Planetary Nebula
CO-WD
ONe-WD
AIC ?
Intermediate-mass
Star (7-11 Msun)
Red Supergiant
Thermonuclear
Explosion?
Electron-Capture
Supernova
Neutron Star
Massive Star
(>11 Msun)
Red Supergiant
Core-Collapse
Supernova
Stellar Cloud
with
Protostars
Black Hole

Electron-capture rate on ^{20}Ne

- Intermediate-mass stars after C burning = degenerate O-Ne core

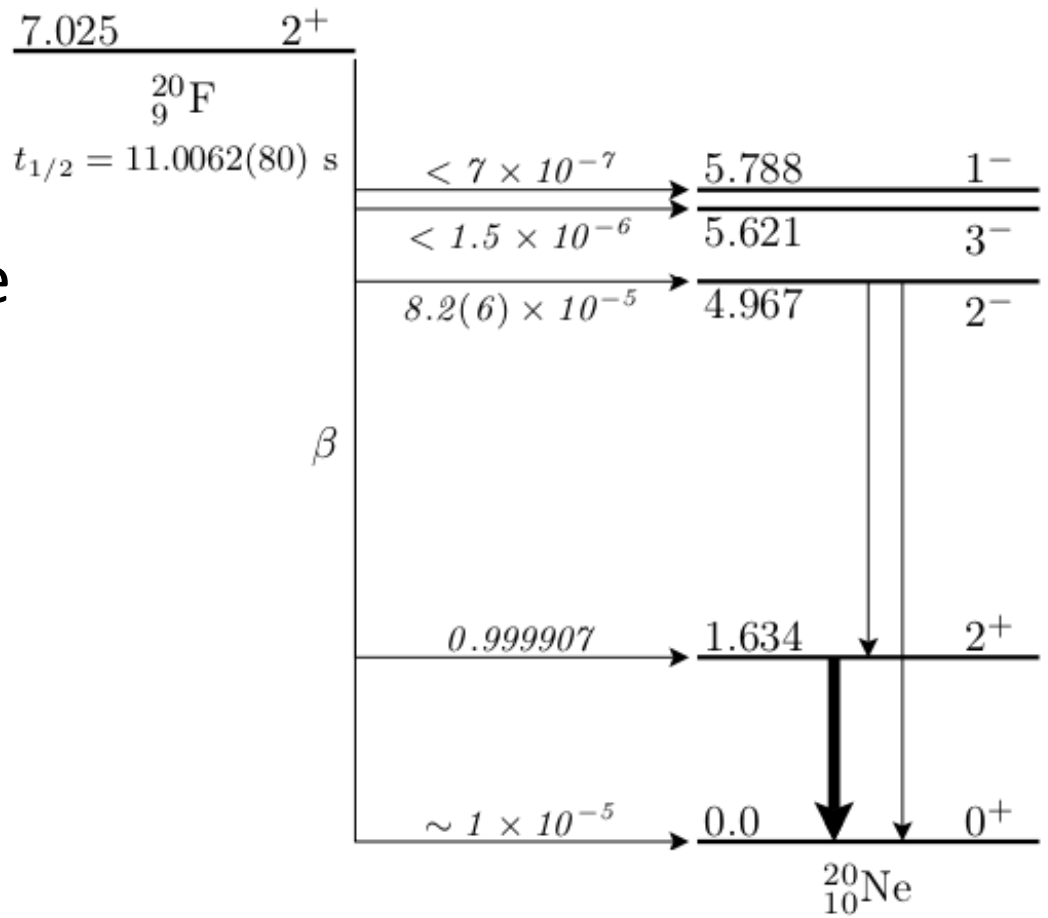
- Electron-capture rates:

  2nd forbitten transition can play a role for the most relevant densities

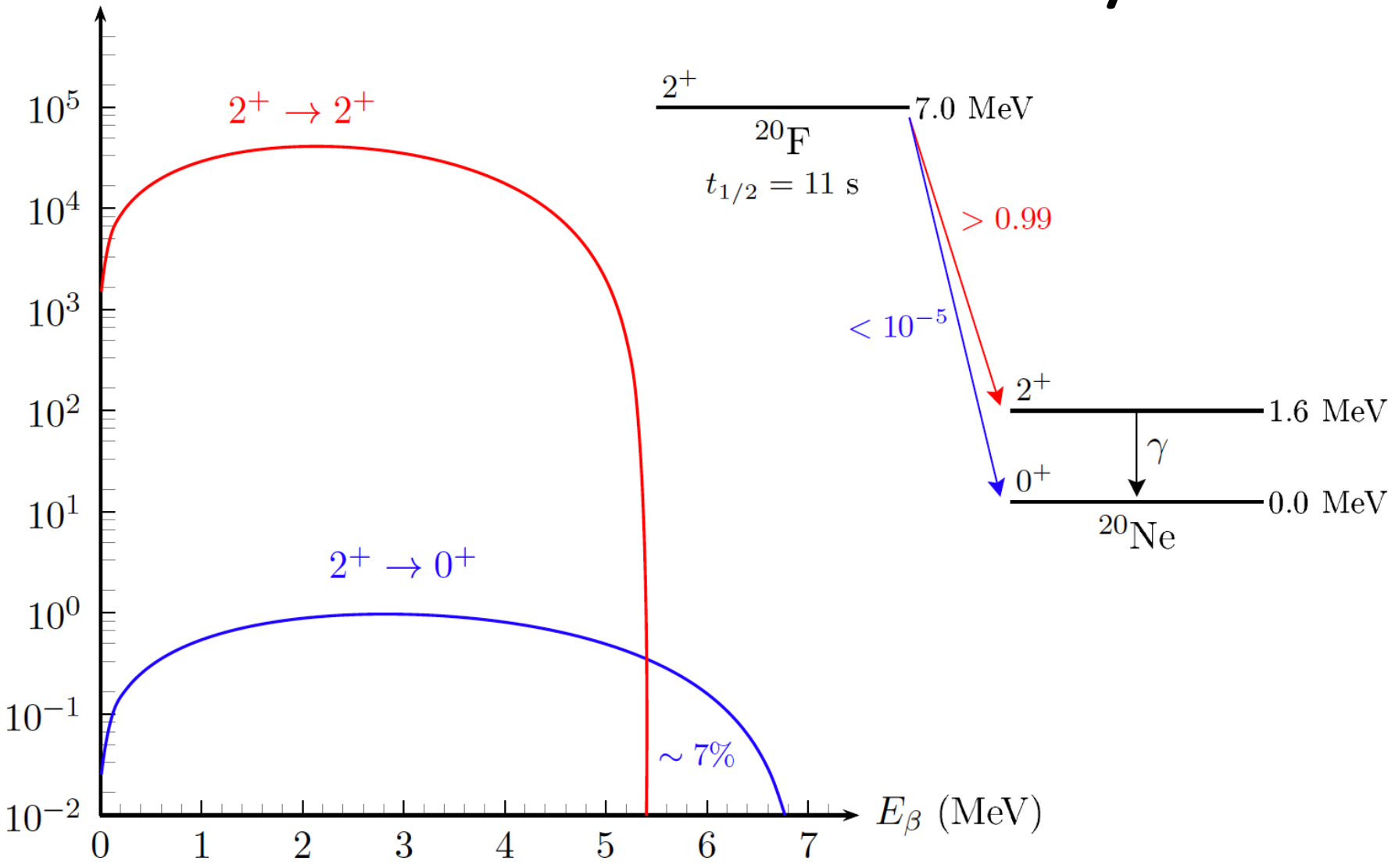


Measurement idea

- Measure 2nd forbitten decay of ^{20}F to ^{20}Ne ground-state
- Previously only upper limit known

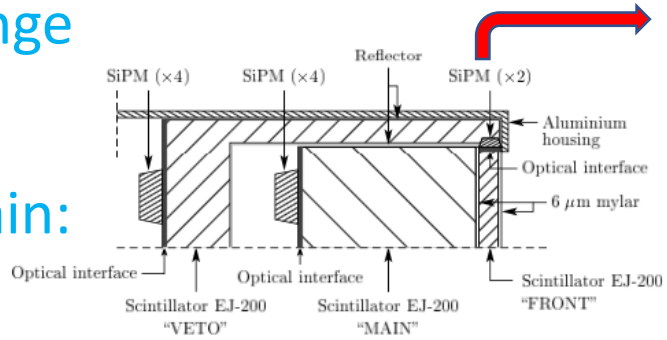


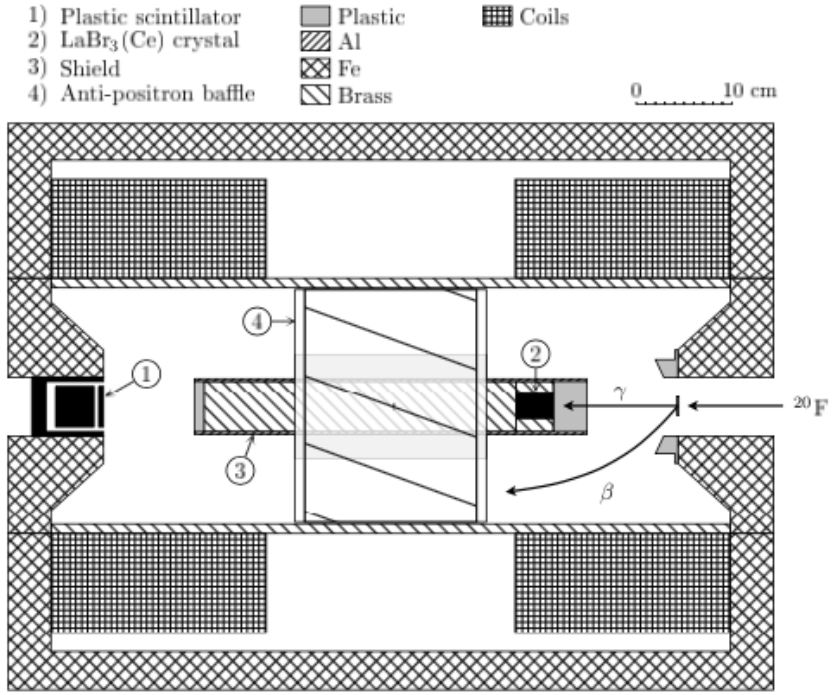
Why is it difficult?



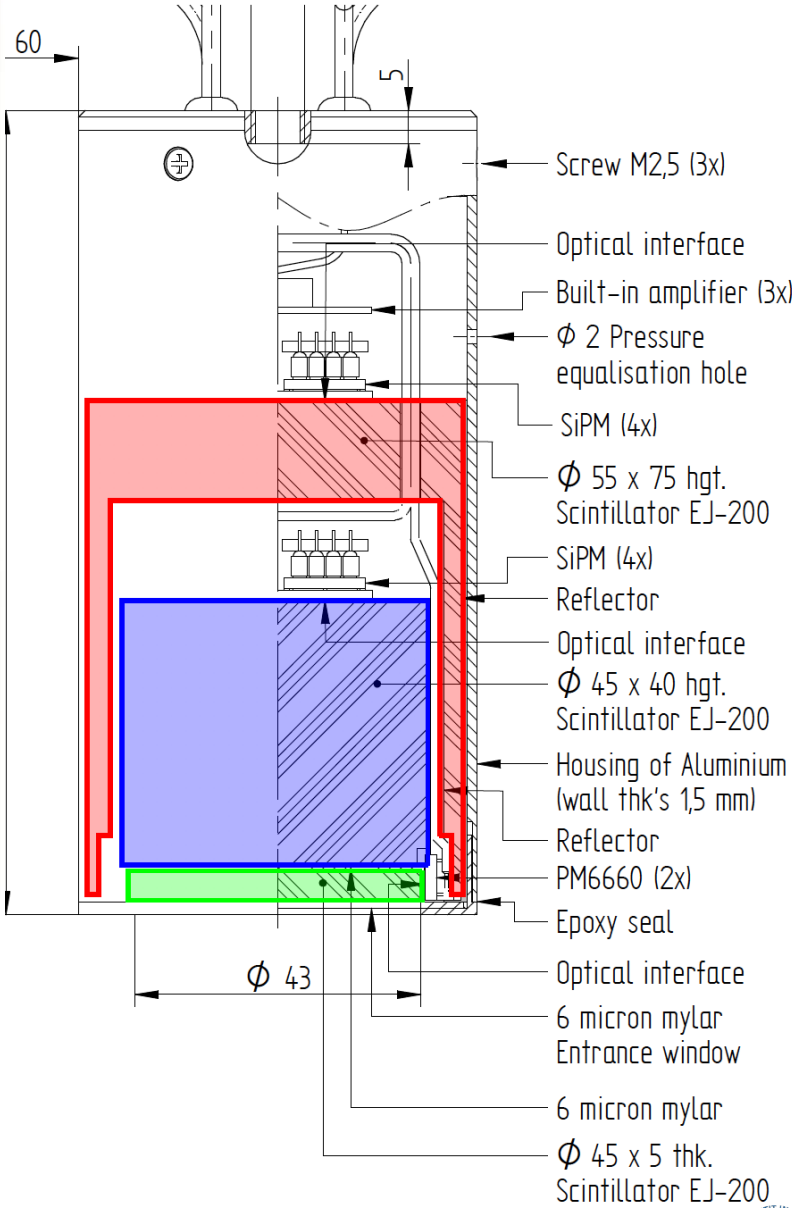
The decay experiment

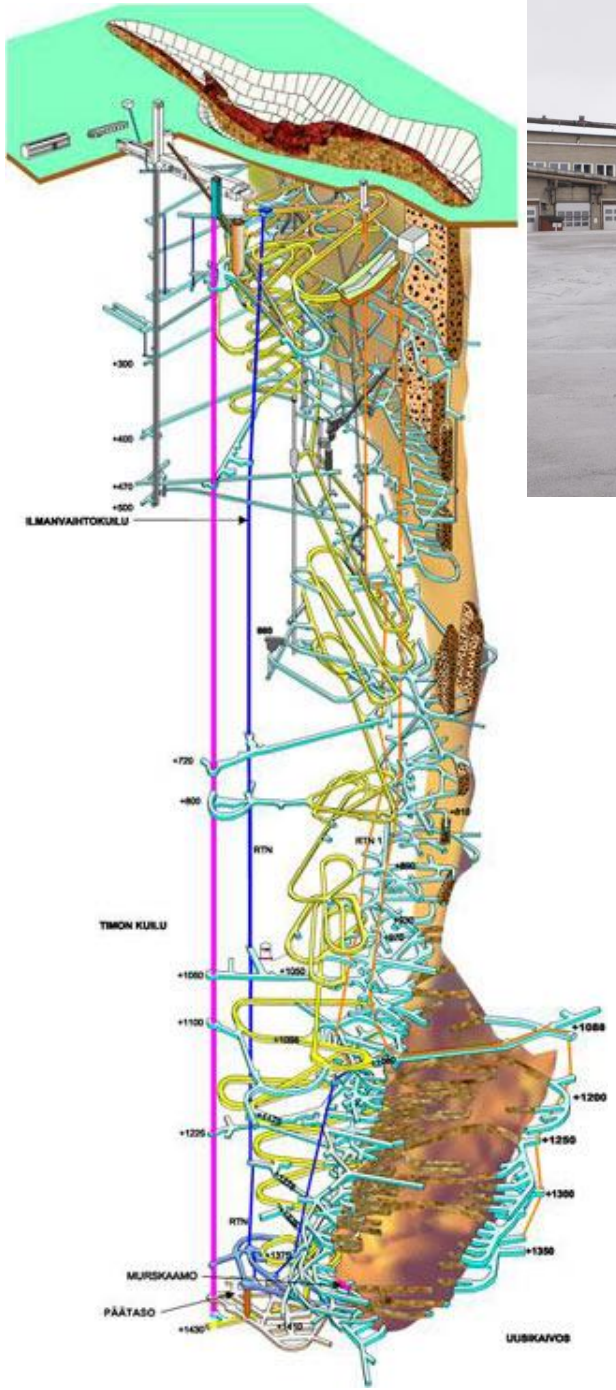
- Radioactive $^{20}F^{+}$ beam at IGISOL-4 / JYFL Accelerator Laboratory
  - (d,p) on BaF_2, ^{12}B (from B) for calibration
  - 30 kV transport, stopped in thin C foil
  - Intensity around 11 kHz
- Magnetic transporter
  - Selects momentum range
- Plastic-scintillator
  - 3 parts: veto, front, main:

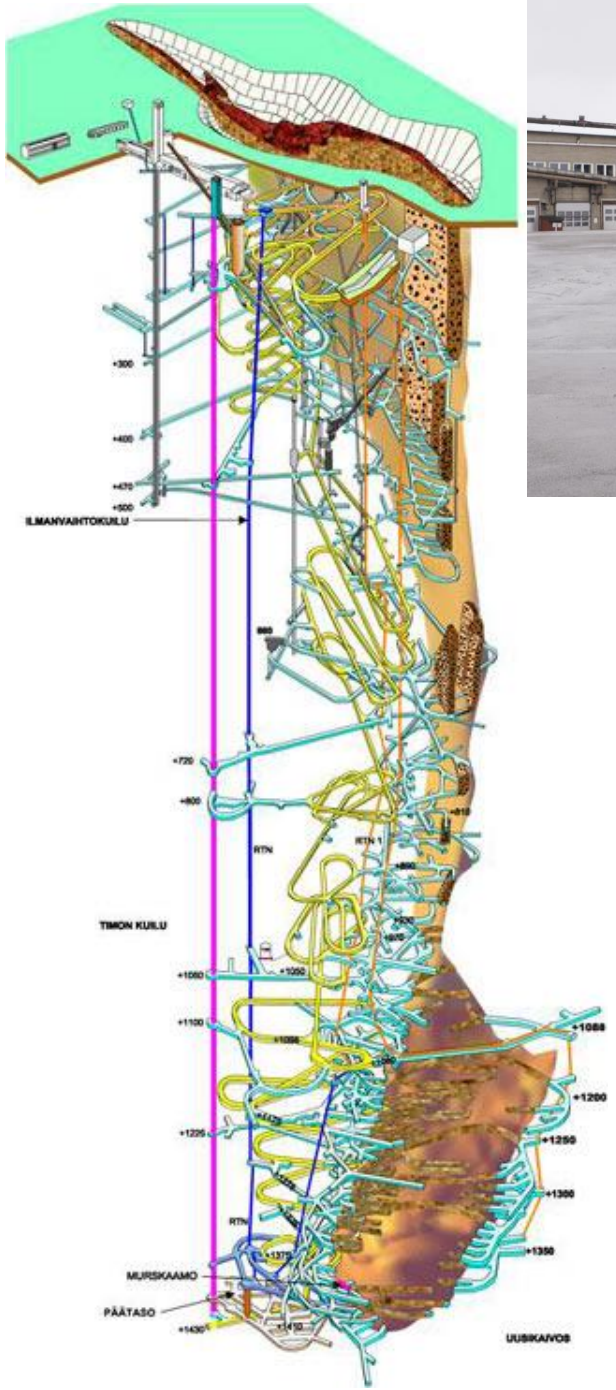





SCIONIX HOLLAND


60
5
Screw M2,5 (3x)
Optical interface
Built-in amplifier (3x)
Φ 2 Pressure equalisation hole
SiPM (4x)
Φ 55 x 75 hgt. Scintillator EJ-200
SiPM (4x)
Reflector
Optical interface
Φ 45 x 40 hgt. Scintillator EJ-200
Housing of Aluminium (wall thk's 1,5 mm)
Reflector
PM6660 (2x)
Epoxy seal
Optical interface
Φ 43
6 micron mylar Entrance window
6 micron mylar
Φ 45 x 5 thk. Scintillator EJ-200


ILMANVAIHTOKUILU
TIMON KUILU
MURSKAAMO
PÄÄTASO
UUSIKAIVOS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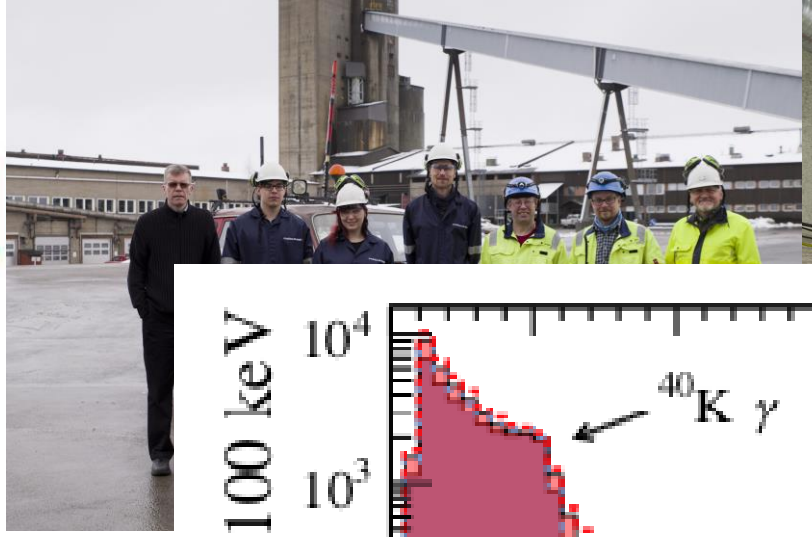
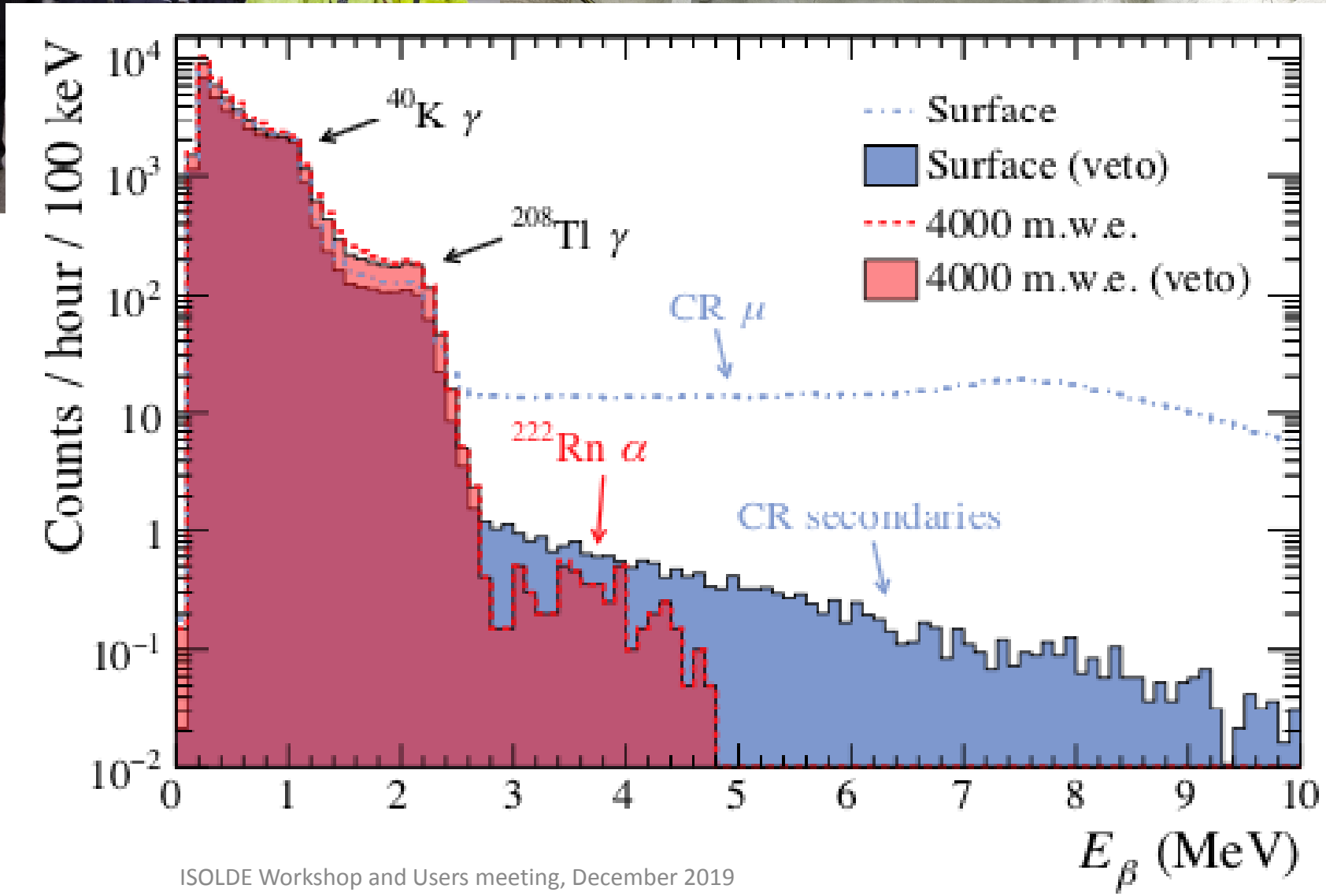
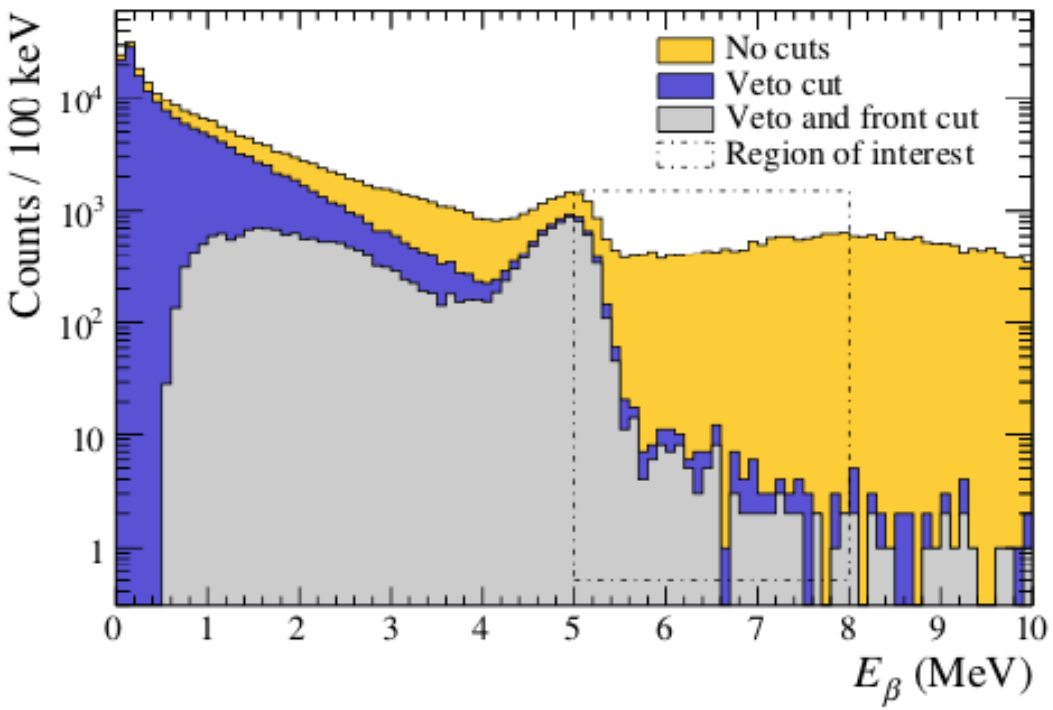
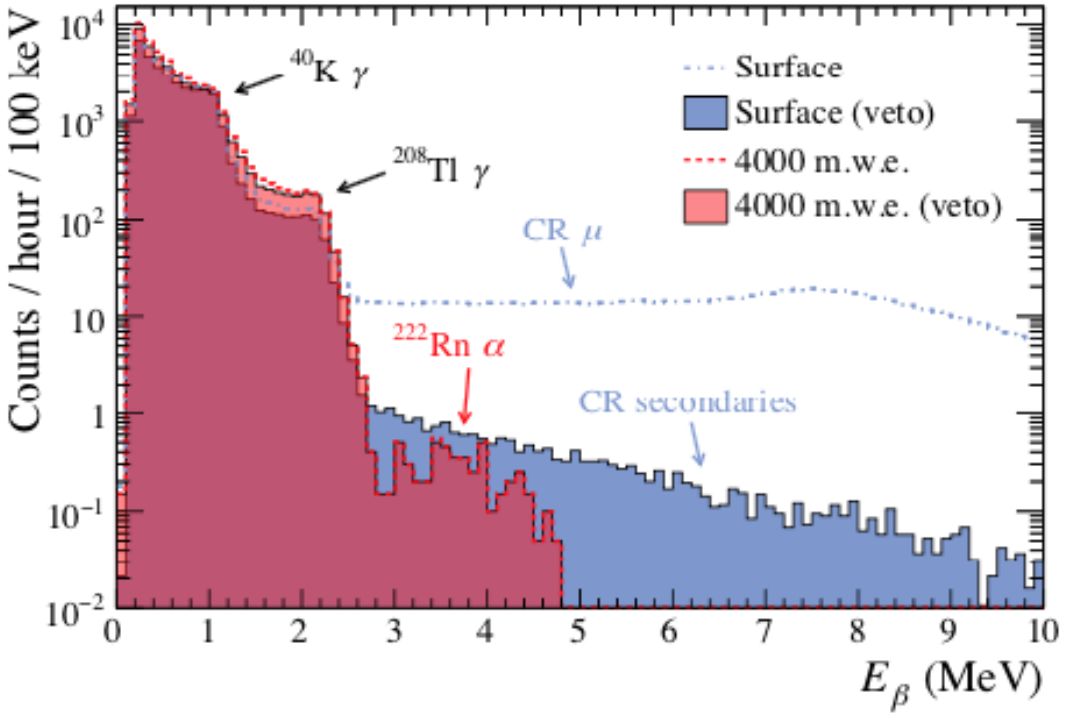



Counts / hour / 100 keV
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
1
2
3
4
5
6
7
8
9
10
E_β (MeV)
^{40}K γ
^{208}Tl γ
^{222}Rn α
CR μ
CR secondaries
Surface
Surface (veto)
4000 m.w.e.
4000 m.w.e. (veto)

Recorded beta spectra

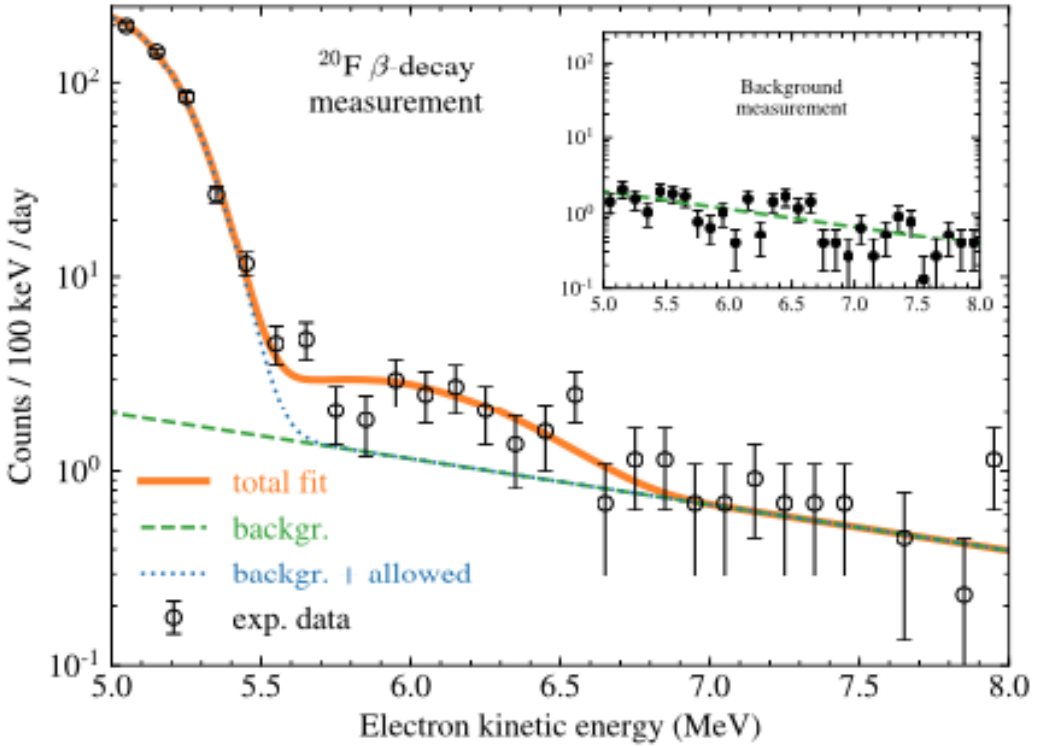
- At 67.7% max current - background (Pyhäsalmi mine)

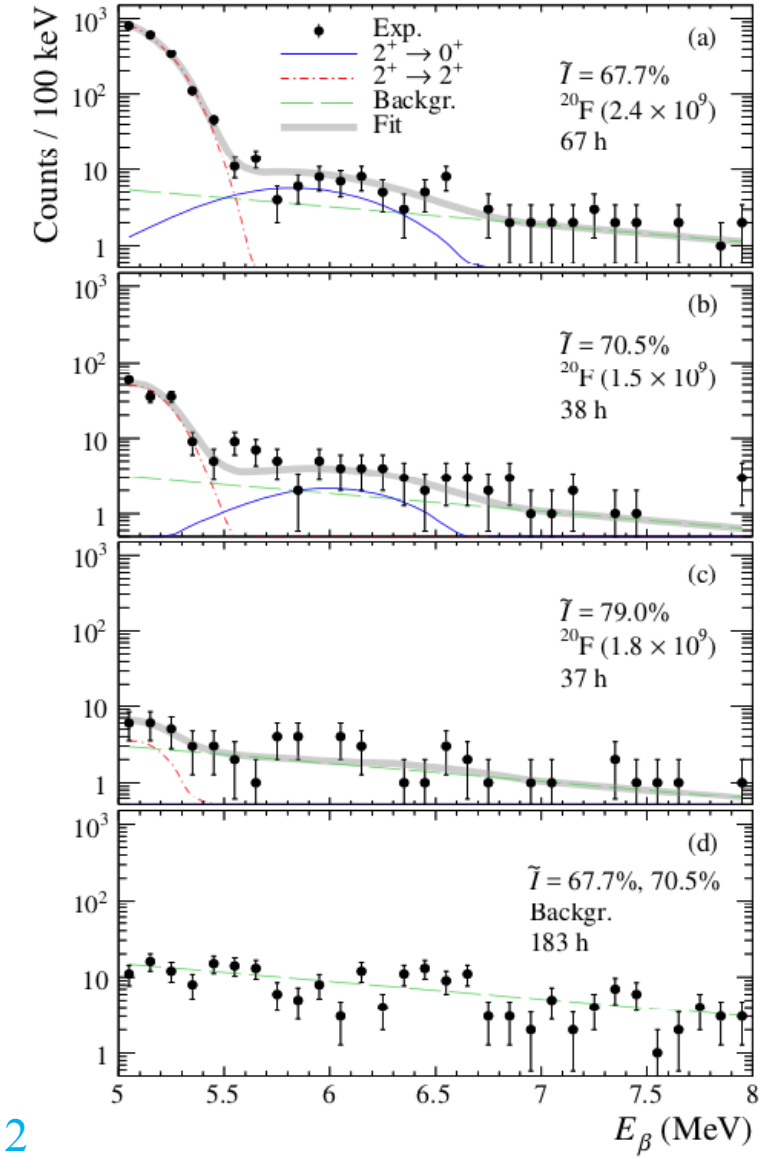




Veto cut = no signal in Veto Front cut = deposited energy 0.65-1.60 MeV in Front

Fit to beta spectra





RoI

Out of RoI

Above RoI

Background

Maximum likelihood fit - - $\chi^2/N = 133.6/112$

Ground state transition ^{20}F to ^{20}Ne

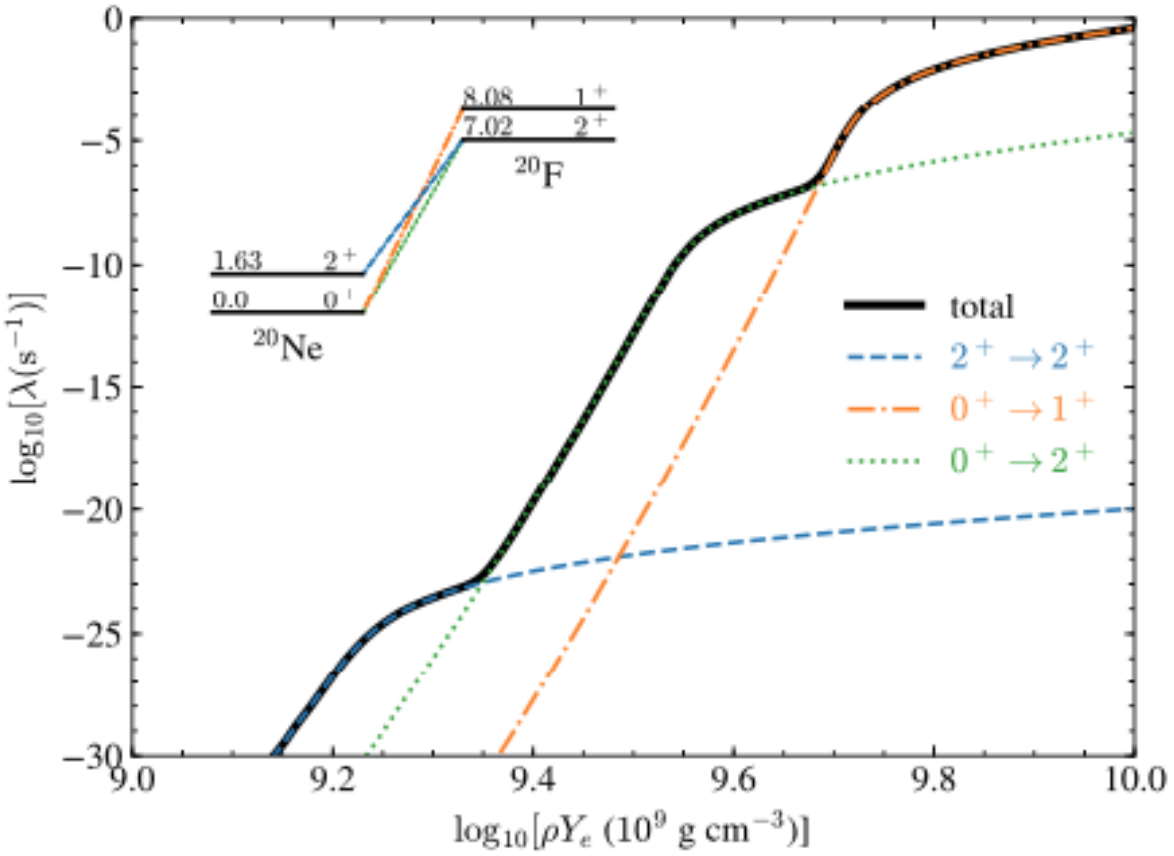
- Calibrations cross-checked with ^{12}B, ^{207}Bi … validated with GEANT4
- Branching ratio: (0.41 +- 0.08 +- 0.07) 10^{-5}
- log(ft) = 10.89(11), strong second-forbidden non-unique transition
- Several shell-model calculations (IM-SRG, CCEI, USDB) agree within a factor of 2

Deduced electron-capture rate on ^{20}Ne

- Intermediate-mass stars after C burning = degenerate O-Ne core

- Electron-capture rates:

  gs transition plays an essential role



Brief results of stellar modelling

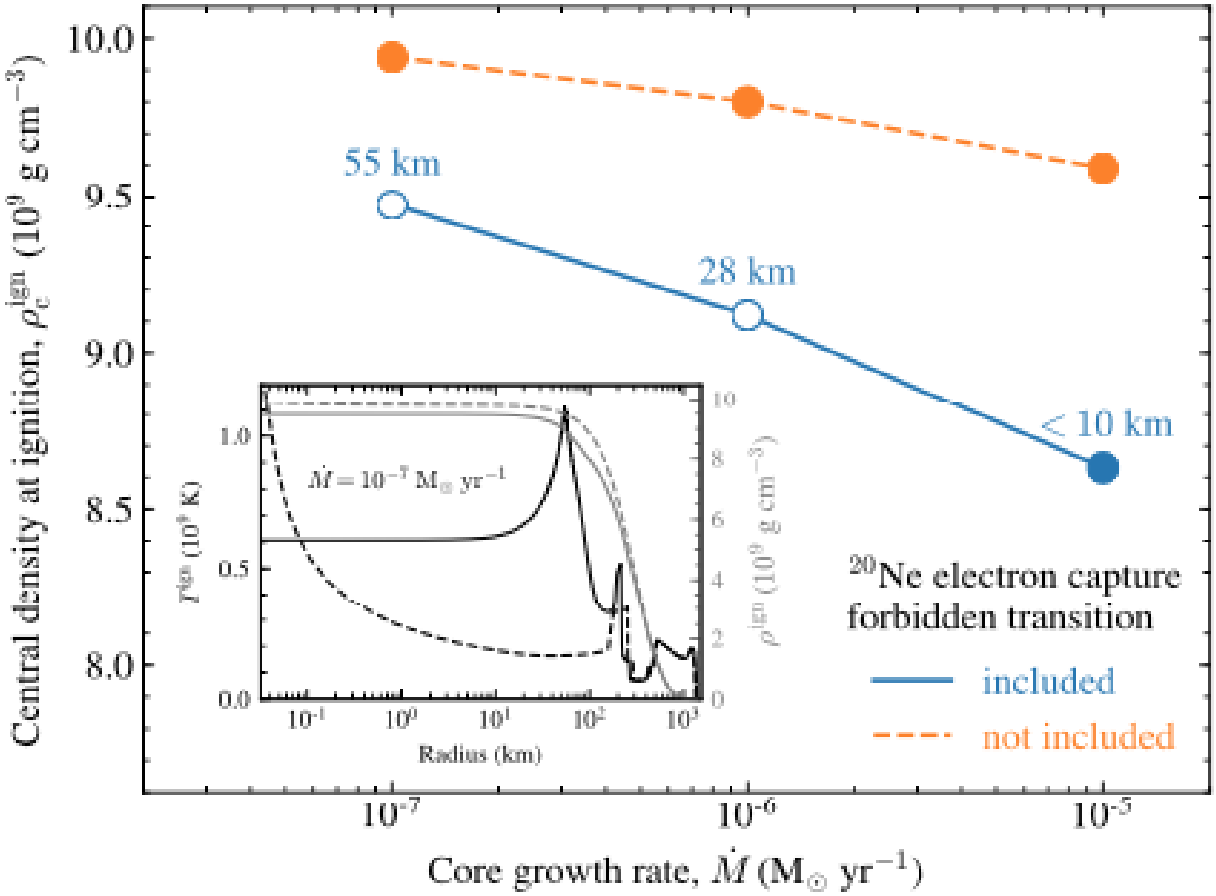
- New gs rate: electron capture on ^{20}Ne proceeds at lower densities

Simulations:

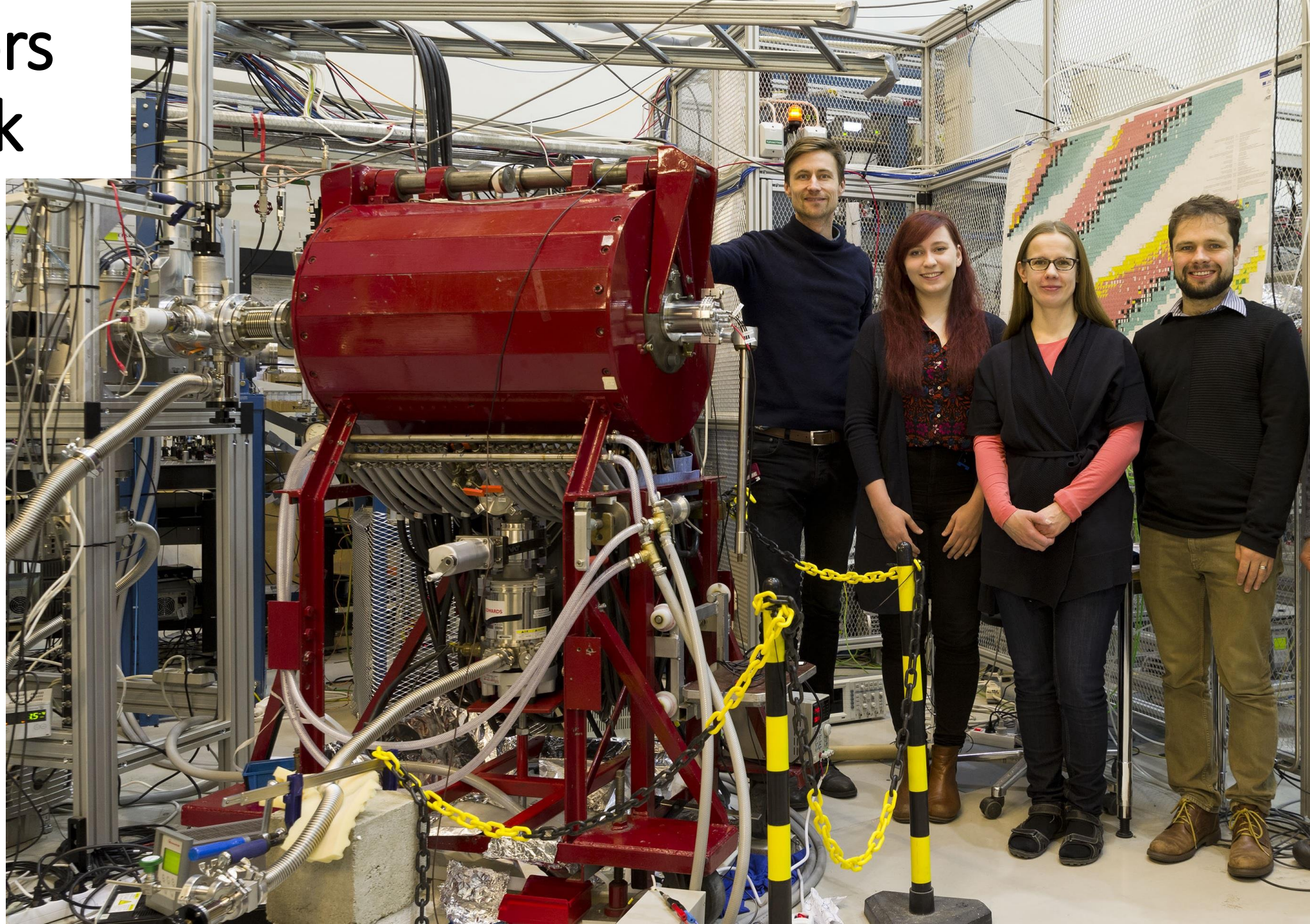
thermonuclear explosion

rather than

gravitational collapse



Contributors to the work



Contributors to the work

arXiv:1805.08149

Measurement of the $2^+ \rightarrow 0^+$ ground-state transition in the β decay of ^{20}F

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Author Contributions The project was born out of discussions between KL, GMP and HOUF. OSK led the experiment, analyzed the data and wrote the paper together with SJ, DFS, GMP, KL and FR; all authors were involved in the project and commented on the paper. DFS and HM performed the MESA simulations. SJ performed the LEAFS simulations with assistance from STO. The electron-capture rates were calculated by DFS, GMP, KL, AI and BAB. The experiment was carried out by OSK, MH, AK and SRA under the supervision of WHT and with assistance from TE, AJ, IM, HP and JÄ. Finally, HOUF and KR helped with the data analysis.

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Discovery of exceptionally strong nuclear transition sheds new light on the fate of intermediate-mass stars

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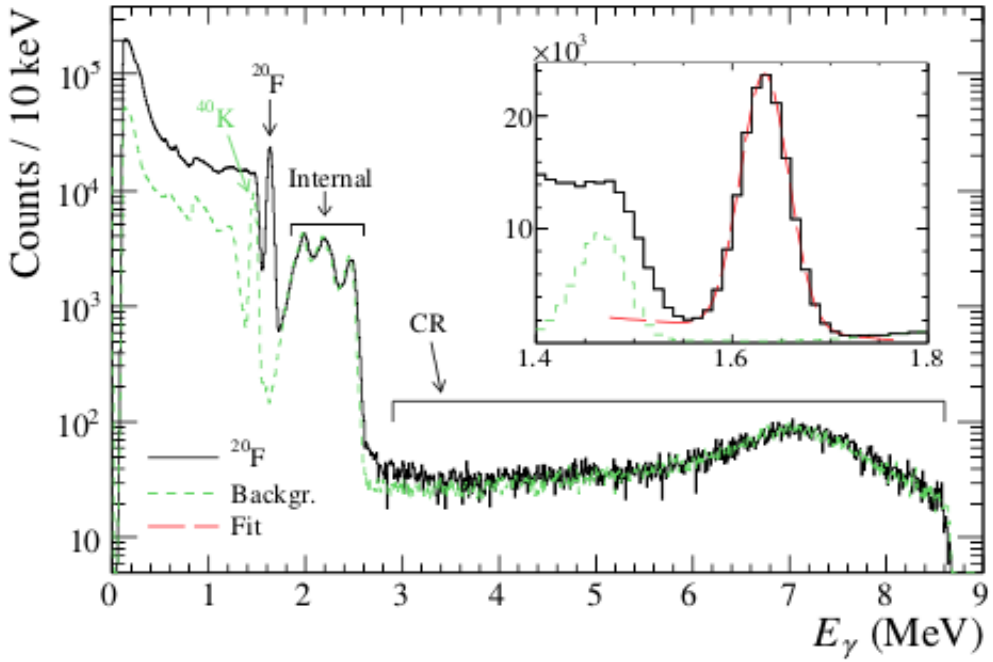
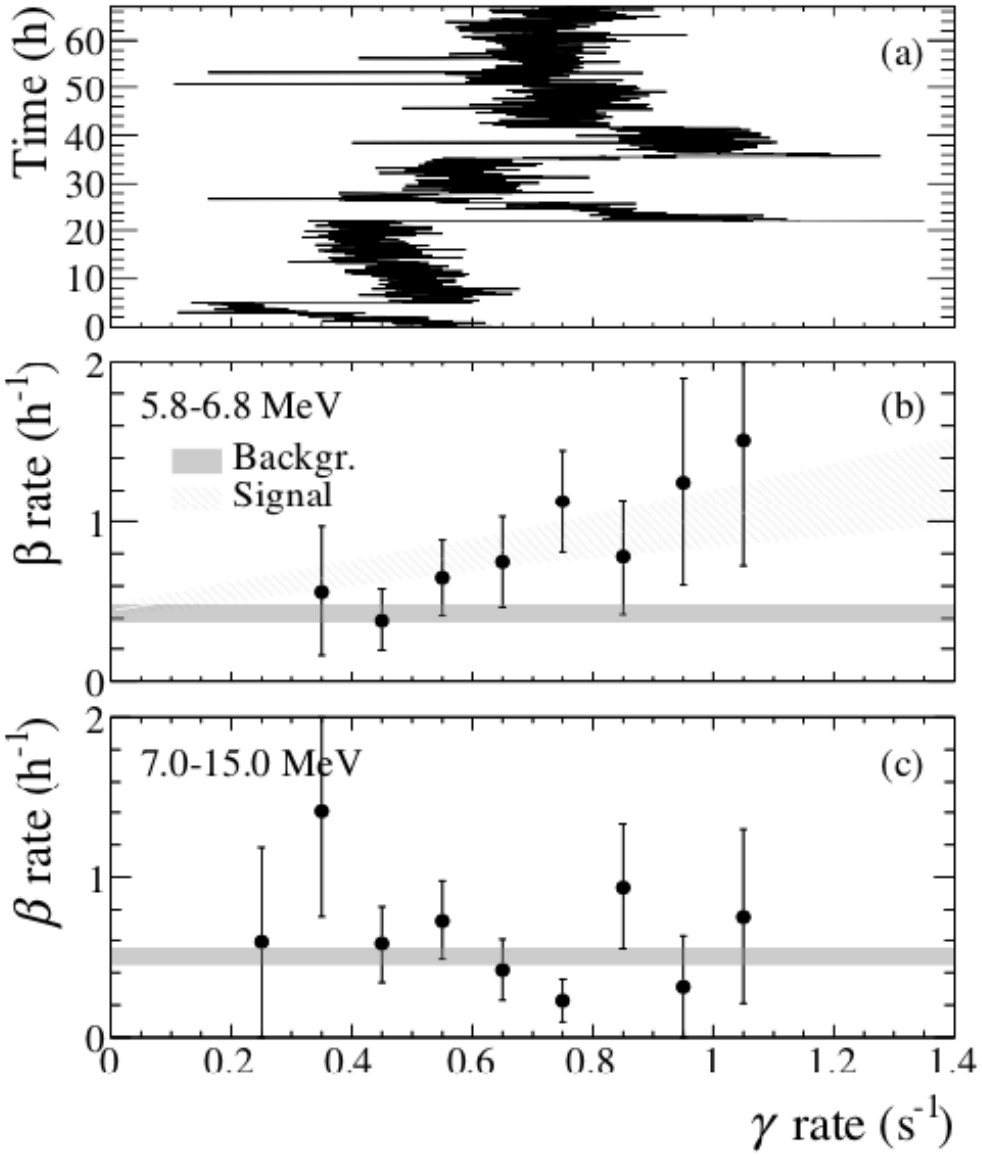
Extras

Gamma spectra



LaBr$_3$(Ce) detector



Modelling extras

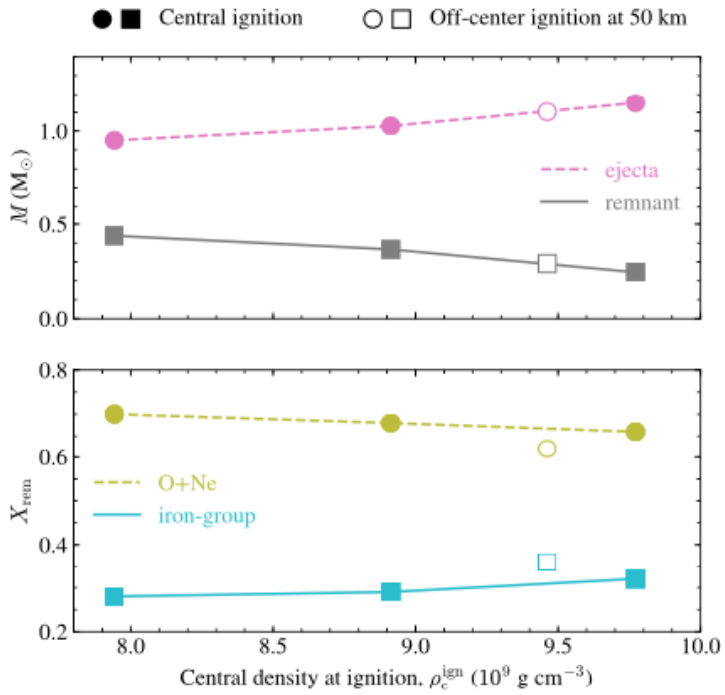


FIG. 4. Mass (M) of bound remnant and ejecta and mass fractions (X) of oxygen + neon and iron-group elements in the remnant are shown as a function of the central density at ignition ($\rho_c^{\rm ign}$). Filled markers denote simulations with central ignition; empty markers denote simulations with ignition occurring in a sphere with radius of 50 km.

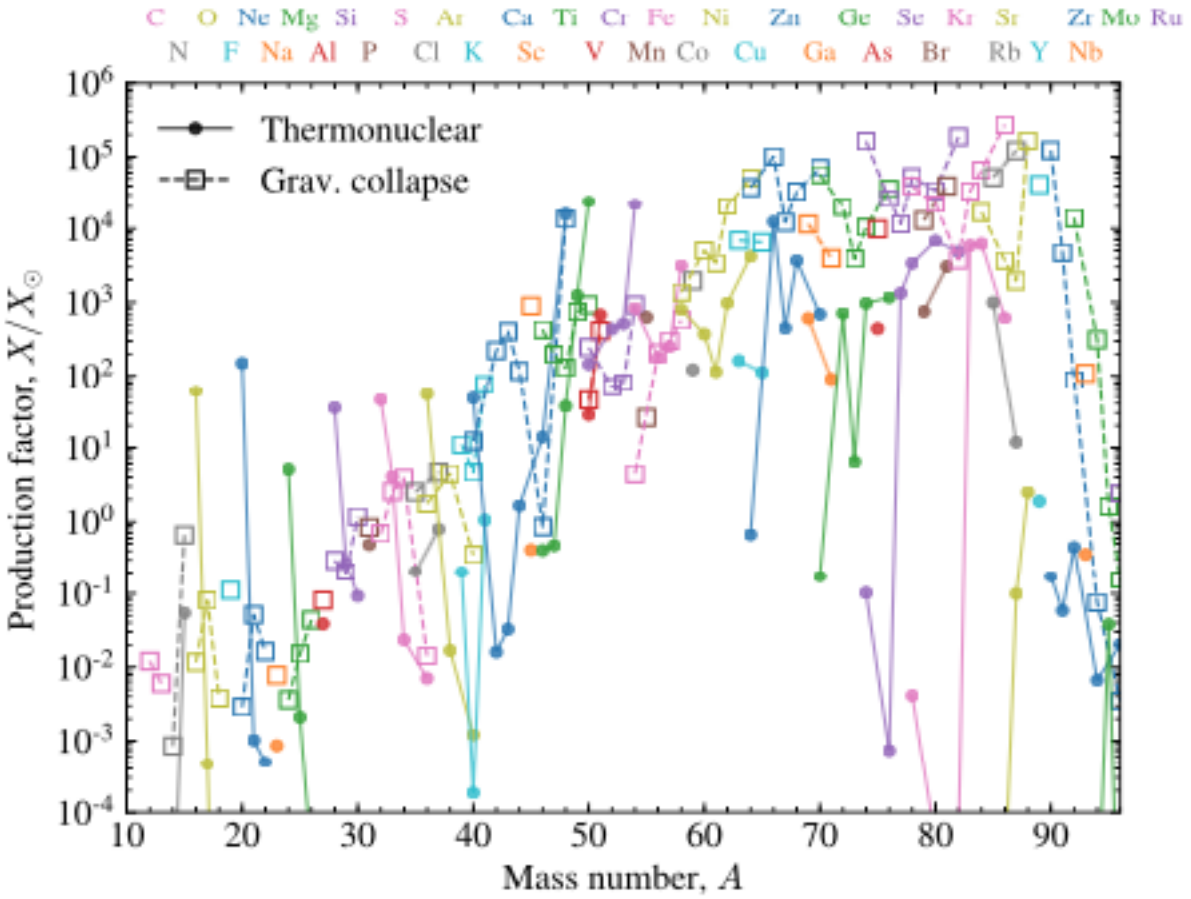


FIG. 5. Mass fraction relative to solar, $X/X_\odot$, of stable isotopes in the ejecta of the (off-center) thermonuclear explosion compared to the gravitational collapse of Ref. [45].

Shape of beta spectrum

- Depends on detailed matrix elements…